

A Concept for a Joint NASA/ESA Mission for In Situ Exploration of an Ice Giant Planet

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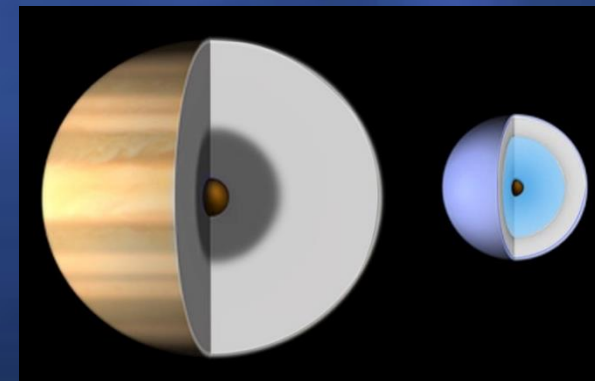
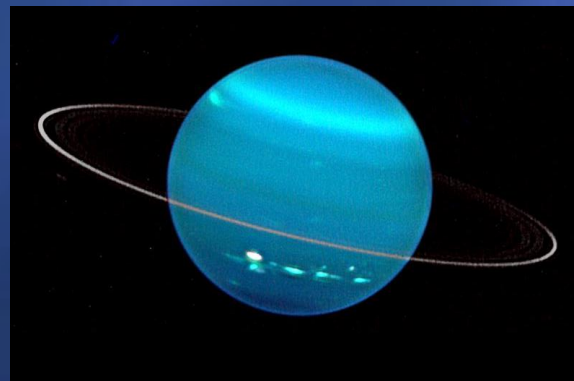
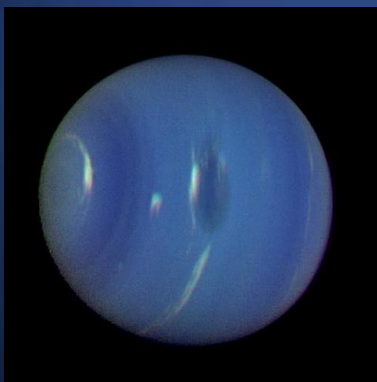
15th International Planetary Probe Workshop
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June 2018

Science Justification for Outer Planet Entry Probes

Comparative planetology of well-mixed atmospheres of the outer planets is key to the origin and evolution of the Solar System, and, by extension, extrasolar systems.

Atreya, S. K. et al., "Multiprobe exploration of the giant planets – Shallow probes", Proceedings of the 3rd International Planetary Probes Workshop, Anavyssos, Greece, 2005.

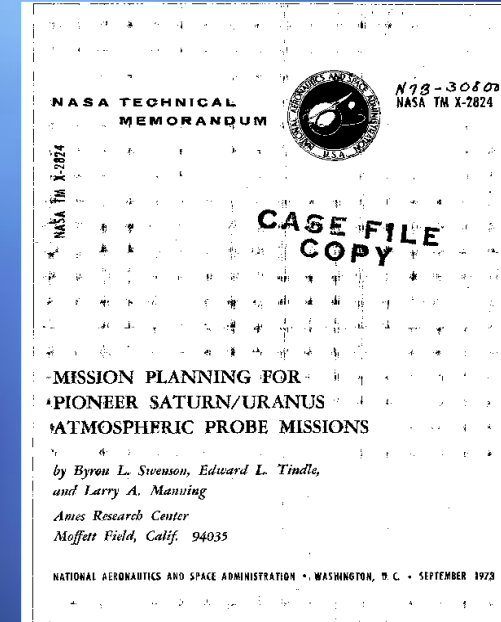
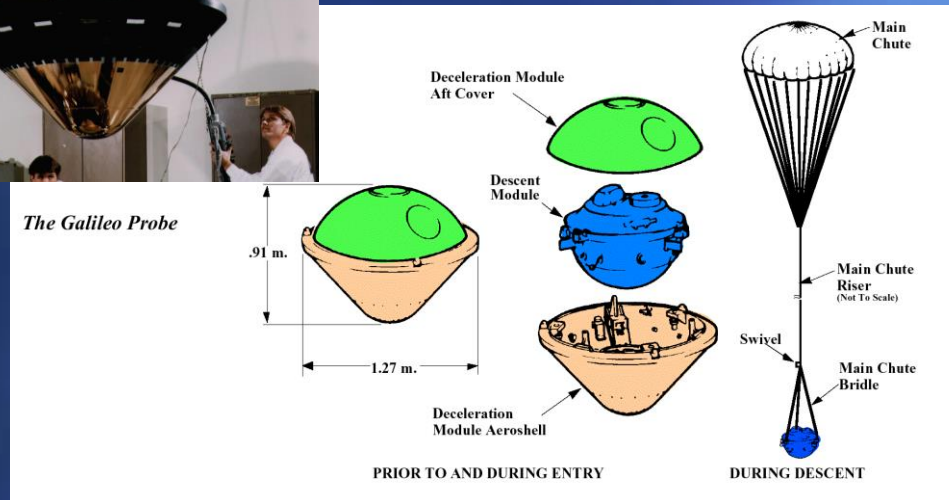
For all the capabilities of remote sensing, only *in situ* exploration by descent probe(s) can completely reveal the secrets of the deep, well-mixed atmosphere containing pristine materials from the epoch and location of ice giant formation.



Heritage and Previous Studies

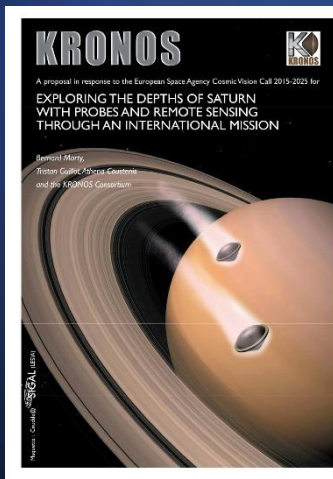


Galileo Probe



NASA 1973

ESA KRONOS
Proposal

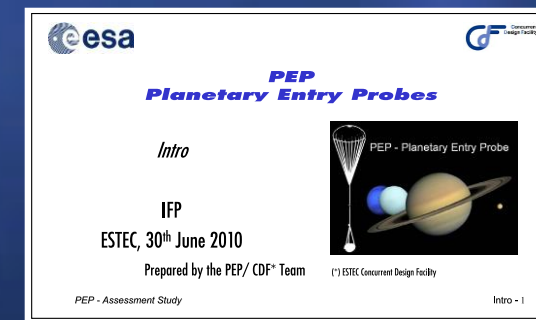


June 15, 2018

ESA Huygens Probe



Predecisional - For planning and discussion purposes only.



ESA PEP
Study

SPRITE

Saturn Probe Interior and Atmosphere Explorer

NASA New Frontiers 4
Amy Simon, PI

Hera Saturn Entry Probe Mission

*A Proposal in Response
to the ESA Call for a
Medium-size mission opportunity
in ESA's Science Programme
for launch in 2029-2030 (M5)*

Olivier J. Mousis,
David H. Atkinson
and the Hera Team

October 5, 2016



Saturn Entry Probe Potential

for Uranus and Neptune Missions

Thomas R. Spilker, *Jet Propulsion Laboratory / CIT*

David H. Atkinson, *Univ. of Idaho*

9th International Planetary Probes Workshop

Toulouse, France

2012 June 18



Ice Giant Probe Mission Concept

Release:

- 60 days prior to entry
- Spin stabilized
- RHUs for coast heating

Uranus/Neptune Entry

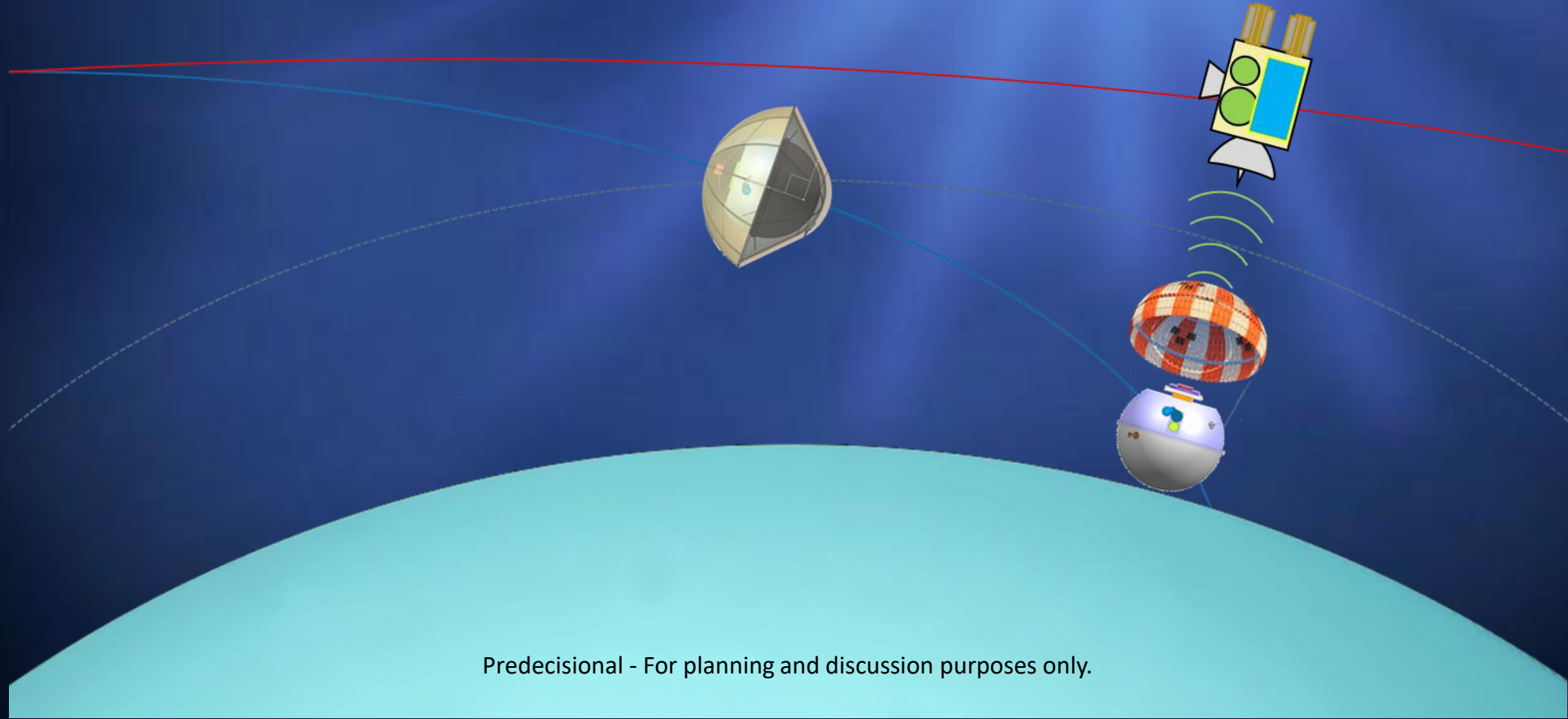
Entry $V = 23.5/24.1$ km/s
FP Angle = $-30/-20$ deg

Telecomm to

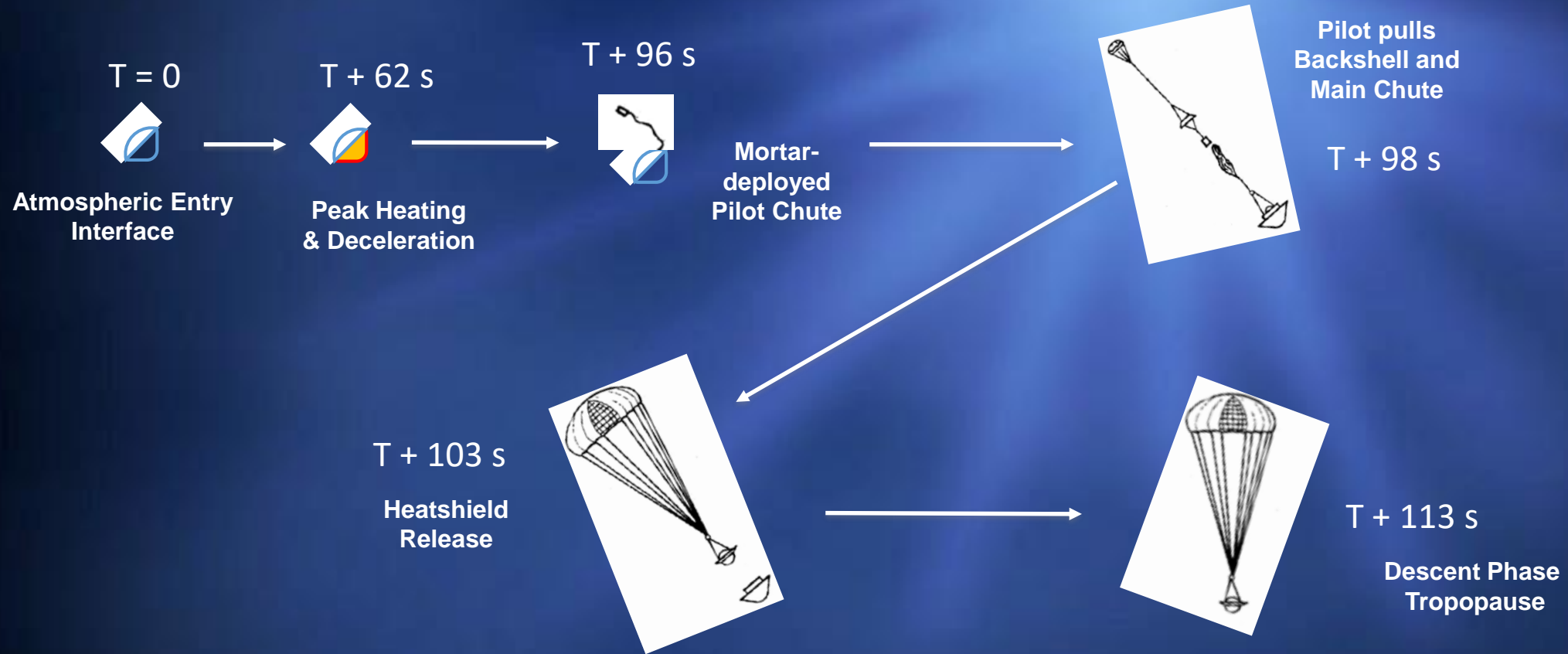
Carrier Relay Spacecraft

Duration: >1 hr

Max Range: $<100,000$ km

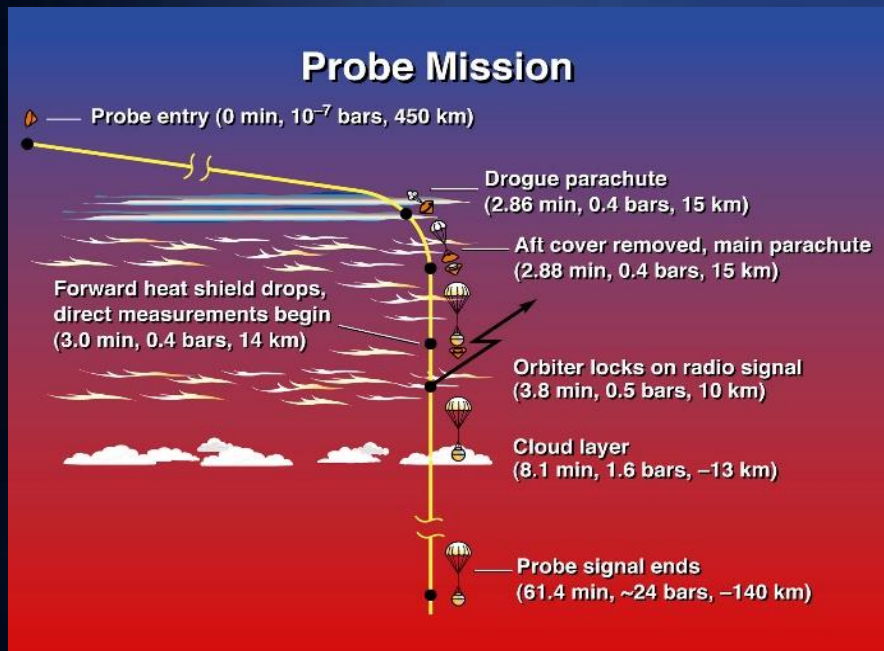


Ice Giant Entry Sequence



Core Mission Profile

HEEET (provided by NASA) would enable significant mass savings over Carbon-Phenolic for range of EFPA's



Galileo entry, descent and deployment sequence provides basis for proposed future Ice Giant missions.

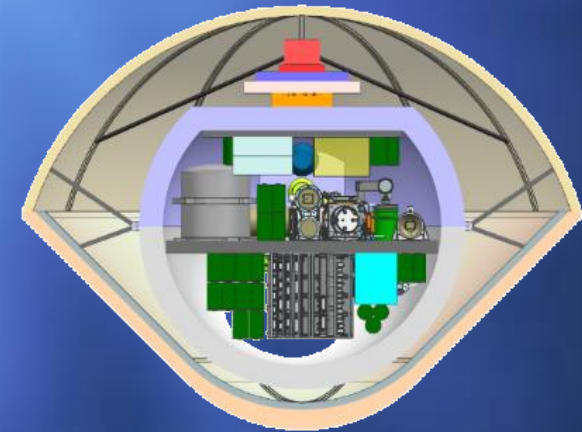
Table E.1 Entry System Mass Estimates

| Entry Flight Path Angle (EFPA), degrees | Mass, kg | | | |
|---|-----------------|-----------------|-----------------|-----------------|
| | -8 | | -19 | |
| TPS Material | HEEET | Carbon Phenolic | HEEET | Carbon Phenolic |
| Entry System (total mass) | 215 | 255 | 199 | 223 |
| Deceleration module | 92.6 | 132.6 | 76.6 | 100.6 |
| Forebody TPS (HEEET) | 40 | 80 | 24 | 48 |
| Afterbody TPS | 10.5 | 10.5 | 10.5 | 10.5 |
| Structure | 18.3 | 18.3 | 18.3 | 18.3 |
| Parachute | 8.2 | 8.2 | 8.2 | 8.2 |
| Separate Hardware | 6.9 | 6.9 | 6.9 | 6.9 |
| Harness | 4.3 | 4.3 | 4.3 | 4.3 |
| Thermal Control | 4.4 | 4.4 | 4.4 | 4.4 |
| Descent Module | 122.7 | 122.7 | 122.7 | 122.7 |
| Communication | 13 | 13 | 13 | 13 |
| C&DH Subsystem | 18.4 | 18.4 | 18.4 | 18.4 |
| Power Subsystem | 22 ¹ | 22 ¹ | 22 ¹ | 22 ¹ |
| Structure | 30 | 30 | 30 | 30 |
| Harness | 9.1 | 9.1 | 9.1 | 9.1 |
| Thermal Control | 4.3 | 4.3 | 4.3 | 4.3 |
| Science Instrument | 25 | 25 | 25 | 25 |
| Separate Hardware | 0.9 | 0.9 | 0.9 | 0.9 |

Note. Deceleration of (or Entry System) module 1m diameter aeroshell, 36 km/s inertial velocity, 10 deg latitude). The descent module mass estimate, except for the Science Instruments, are the same as that of Galileo Probe. Additional mass savings are likely when the descent system structure is adjusted for reduction in scale as well as entry g-load. Galileo design-to g-load was 350. Saturn probe entry g-load with 3-sigma excursions will be less than 150 g's.

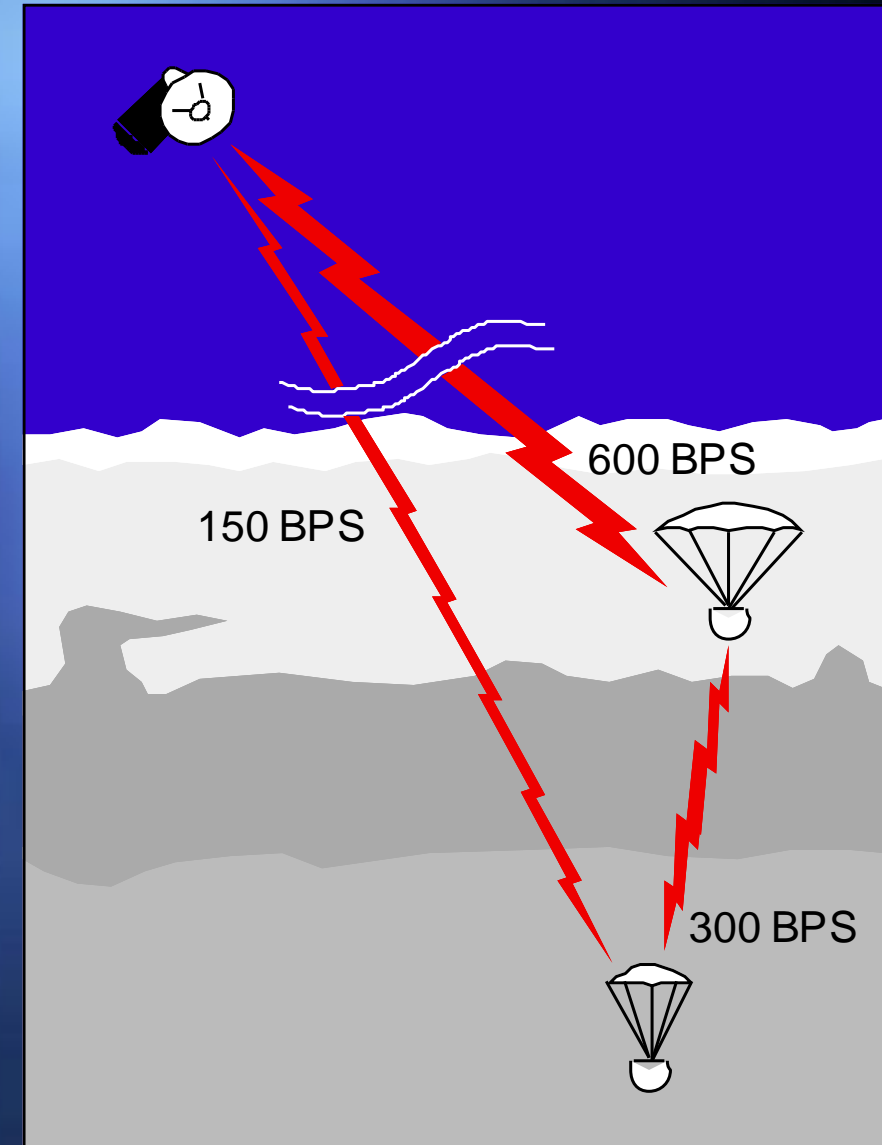
Probe Science Payload

| Instrument | Measurement |
|--|---|
| Mass Spectrometer (MS) | Elemental and chemical composition including noble gases and key isotopes |
| Atmospheric Structure Instrument (ASI) | Pressure and Temperature, Entry and Descent Accelerations → Density |
| Radio Science Experiment | Atmospheric dynamics: winds and waves; atmospheric absorption → composition |
| Nephelometer | Cloud structure, aerosol number densities and characteristics |
| Net Flux Radiometer | Net radiative fluxes: upwelling thermal IR, solar energy |
| Helium Abundance Detector | Helium Abundance |



Deep Probe Telecommunications: Staged Probes

- Outer planet atmospheres primarily H_2/He but with significant radio-absorbing species: NH_3 , H_2O
- At UHF frequencies, shallow probes (10-20 bars) remain within relatively “clear” atmosphere → low opacity
- Communication through deep absorbing atmospheric overhead → greatly reduced data throughput.
- Architecture: Shallow probe descending slowly releases deep probe for rapid descent.
- Telecommunications: Potential to overcome deep RF opacity to limit significantly reduced data rates.

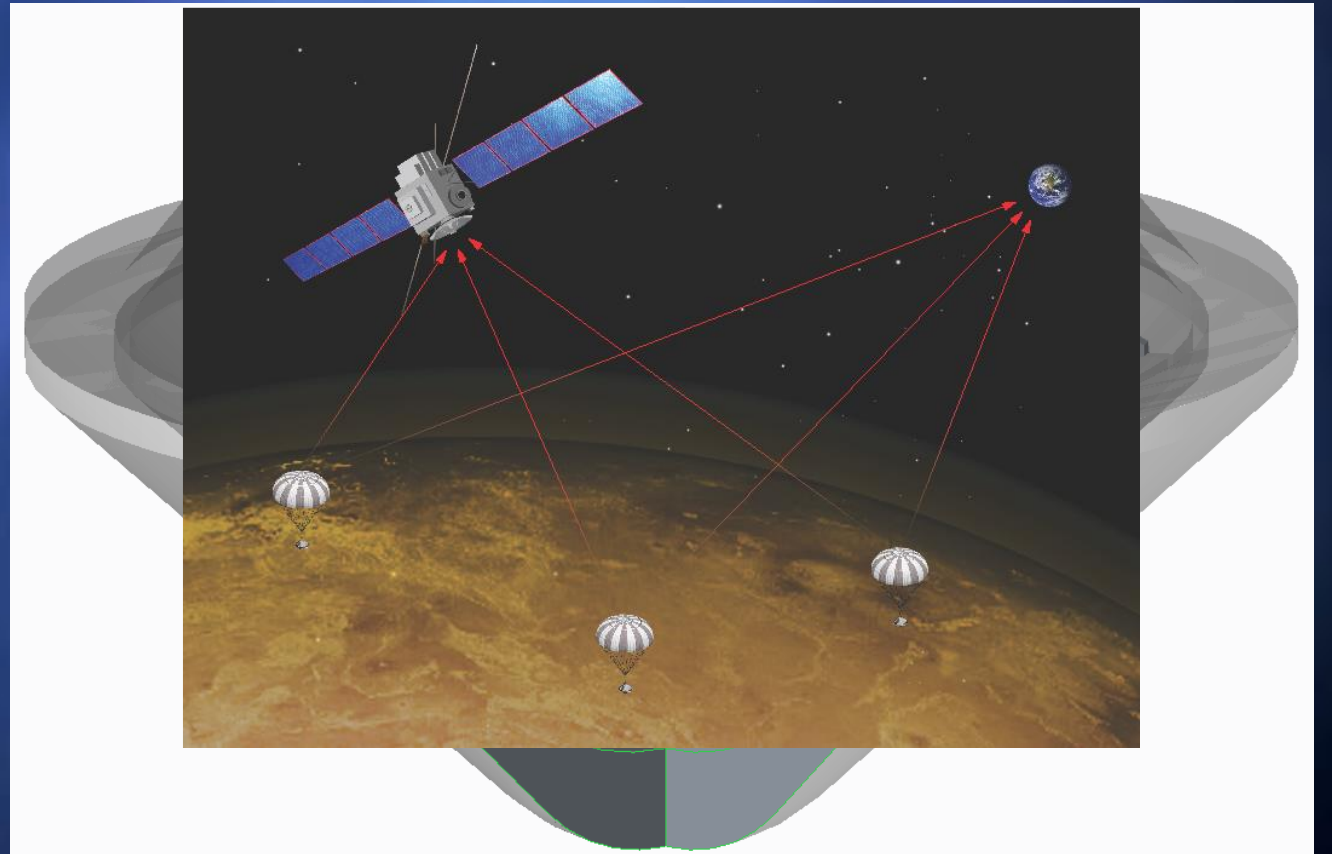


Small Secondary Probes

Secondary probe to complement a primary probe mission to provide in situ measurements of spatially varying atmospheric structure, dynamics, and properties

- Mass: 30 kg, Diameter: 50 cm
- Power: Primary Batteries
- Heatshield: HEEET
- Depth: 5-10 bar

PSDS3 SNAP (Small Next Generation Atmospheric Probe, Sayanagi, et al.) design concept enables future small multiprobe missions, or as a 2ndary probe flying in tandem with a primary probe.



Summary

- The Giant Planets played a significant role in shaping the architecture of the solar system and the evolution of the terrestrial planets.
- With the exception of in situ measurements of Saturn's atmospheric composition, the Jupiter and Saturn systems have been explored in detail. The last largely unexplored class of planets is the Ice Giants.
- Remote Sensing is a very powerful technique, but is unable to measure essential components of the atmosphere, noble gases and key isotopes in particular.
- The legacy of the highly successful Galileo probe mission directly translates to concepts for future giant planet entry probe missions. Over the past decade, significant effort has been put into developing concepts for Saturn entry probe missions.

Future in situ explorations of the ice giants will draw heavily on the experience of Galileo, and the Saturn probe mission concept studies.

SEARCH AND DISCOVERY

Galileo's Probe Sends a Weather Report from Jupiter

Analyzing data from the Galileo spacecraft, which has been orbiting Jupiter since 7 December 1995, is not a job for those who require instant gratification. Delayed for three years after the Challenger disaster, the spacecraft then spent six years in its 3-billion-kilometer journey to the Solar System's largest planet. Moreover, because Galileo's high-gain antenna never fully unfurled, the spacecraft must instead transmit data using its low-gain antenna—at the glacially slow rate of a few tens of bits per second. When one knows as little about a system as we do about Jupiter, however, a trickle of data can unleash a flood of new results. The most recent results,¹⁻¹¹ based on *in situ* measurements of Jupiter's atmosphere and innermost magnetosphere by Galileo's probe, have raised questions about the giant planet's composition, even as they have resolved some fundamental questions about the driving force of the zonal, or east-west, winds that give rise to the planet's banded appearance. Because of Jupiter's large size, and because it is thought to have a near-protosolar composition, these results may have important implications not just for our understanding of Jupiter and similar planets, but also for our ideas on the formation and evolution of the Solar System.

Planning a probe
Perhaps the most amazing aspect of the Jupiter-probe mission is that it was possible at all. Calculations showed that inserting the probe into the Jovian atmosphere near the equator, with a velocity component parallel to Jupiter's rotation, would reduce its entry velocity relative to the atmosphere sufficiently for it to survive the resulting accelerations (over 2200 m/s²) and temperatures (about 14 000 K). Nevertheless, the probe designers faced some difficult trade-offs.

One trade-off involved the number of probes: A single probe could provide detailed information from a single site about temperatures, wind velocities, energetic particles, atmospheric composition, lightning activity, cloud characteristics and radiative fluxes. Multiple probes could provide less information about any one site, but might return information more representative of the planet (or at least its equatorial region) as a whole. The

The first ever *in situ* measurements of Jupiter's atmosphere reveal conditions to be dry and windy, but is this true globally or just the result of local weather?

designers ultimately selected the single probe, because it maximized flexibility—an important consideration given our limited knowledge of Jupiter's atmosphere—while minimizing cost. As it turned out, the entry site weather, which developed after the release of the probe on 13 July 1995, exacerbated the problems inherent in generalizing measurements of a single probe to the planet as a whole.

Earth-based observations² of the probe entry site showed it to be a relatively dry, cloud-free region of downwelling gas. Although such regions typically cover only 1% of Jupiter's surface, it is probably safe to make some important generalizations based on the probe's measurements.

Hot gas and deep winds

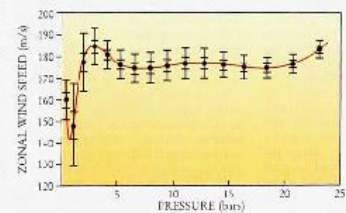
Because they are essentially independent of local weather phenomena at the probe entry site, the probe's measurements of Jupiter's radiation belts and exosphere (or extreme outer atmosphere) are likely to be typical of the planet as a whole. Jupiter's radiation belts exhibited a shell-like structure,¹⁰ with peaks in the particle fluxes outside and inside the planet's bright ring—at about 2.2 and 1.5 Jupiter radii (about 157 000 and 107 000 km, respectively). At 1.35 radii, the particle flux fell rapidly to zero, indicating the cursature of the planet's magnetic field lines.

Inside the radiation belts, the temperature, pressure and density of Jupiter's exosphere were all higher than

predicted down to 500 km above the 1-bar pressure level, but agreed fairly well with predictions at lower altitudes.⁵ Given the feebleness of sunlight at Jupiter, the high exospheric temperatures seem to imply that some other energy source is important in the outer exosphere.

Even some of the measurements made deep in Jupiter's atmosphere clearly have important general implications. Researchers have long argued about whether Jupiter's zonal winds are merely a surface phenomenon, driven primarily by solar radiation, or whether they are powered by energy from Jupiter's interior and hence extend deep into the Jovian atmosphere. The Doppler shifts of the probe's radio signal recorded by the Galileo orbiter showed that Jupiter's zonal winds persist steadily at around 180 m/s down at least to the 20-bar pressure level.^{3,4} (See the figure below.) Because little sunlight can penetrate to such depths, the winds must almost certainly be driven primarily by convective energy from within Jupiter rather than from outside it.

In the 1970s, Friedrich Busse (University of Bayreuth) constructed a model in which Jupiter's rapid rotation rate, coupled with the spherical boundaries of the planet's atmosphere organized its atmospheric convection into a series of cylindrical shells, each shell containing long, thin convective columns aligned with the rotation axis. The intersection of the shells with the planet's roughly spherical outer cloud layers gave rise to its banded pattern of zonal winds. These general ideas have since received support from computer simulations¹² and laboratory experiments.¹³ In 1993, Zi-Ping Sun and Gerald Schubert (University of Califor-



JUPITER'S ZONAL WINDS extend deep into its atmosphere, indicating that they are driven by energy from the interior rather than by sunlight. Wind speeds in this revised profile are about 10% lower than those published in reference 4. (Courtesy of David Atkinson, University of Idaho.)

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